Defence Operational Analysis Symposium 2003

Scheduling Operational-Level Courses of Action

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Outline

- Introduction
  - Characteristics of operational-level planning
  - Motivation of this work
- Operational-level course of action (COA) modelling
  - A conceptual task model
  - Formalising the conceptual model with Coloured Petri Nets
- Model Execution and Analysis
  - COAST demonstration
- Conclusions and future work

Characteristics of Operational-Level Planning

- Operational-level planning is concerned with the orchestration of tactical actions to achieve strategic objectives
- Operational-level planning is characterised with
  - Ambiguity
    - National interest, political aims, strategic objectives, commander's intent, mission
  - Uncertainty
    - Fog of war at the operational-level: own and friendly forces, strategic environment, threat
  - Complexity
    - Coalition operations, NGOs, whole of government approach – other agencies, possible inconsistency and interference between concurrent operations, sequencing and scheduling operations

Major Analytical Steps in Operational-Level Planning

- Determine a desired end-state with constituent conditions
- Develop tasks to achieve the desired end state
- Schedule the tasks
- Analyse options of task schedules for an optimal plan

Motivation

- Develop an appropriate representation of operational-level courses of action (COA) to enable formal analysis for COA sequencing, scheduling and optimisation
- Develop a COA Scheduling Tool (COAST) to demonstrate the formal modelling and analysis concepts
  - And make the formalism transparent to the user

What Is Also Important But NOT Included Here

- Coordination of planning processes
  - Process modelling and analysis
  - process synchronisation techniques
- Information and knowledge management
  - Collaborative planning systems
  - Workflow systems
- Development and Analysis of COA strategies
  - Influence networks, Bayesian networks, policy analysis, COGNET
- COA Simulation (COA Sim) and War Games

A Simple Planning Example

- End State
  - Amphibious forces successfully landed
- Tasks
  - Conduct amphibious assault
  - Conduct combat air patrol
  - Conduct ASW operations in the AO
  - Conduct airborne operations
  - Conduct maritime escort operation
  - Conduct mine clearance operation
  - Establish FOB
  - Establish FARP
  - Provide AAR
- Problem
  - How to sequence and schedule the tasks with assigned resources to achieve the desired end state?

Modelling Considerations

- A well defined military *task* has a *duration*, *preconditions* and *effects*
- A task may require *resources*
  - For example, military forces and logistics
  - Some tasks may consume resources
- The military user may wish to impose *synchronisation* constraints among tasks
- A military end state can be expressed as a set of *conditions*
  - So can concepts such as decisive points (DP)
  - Preconditions, effects and conditions are of the same type

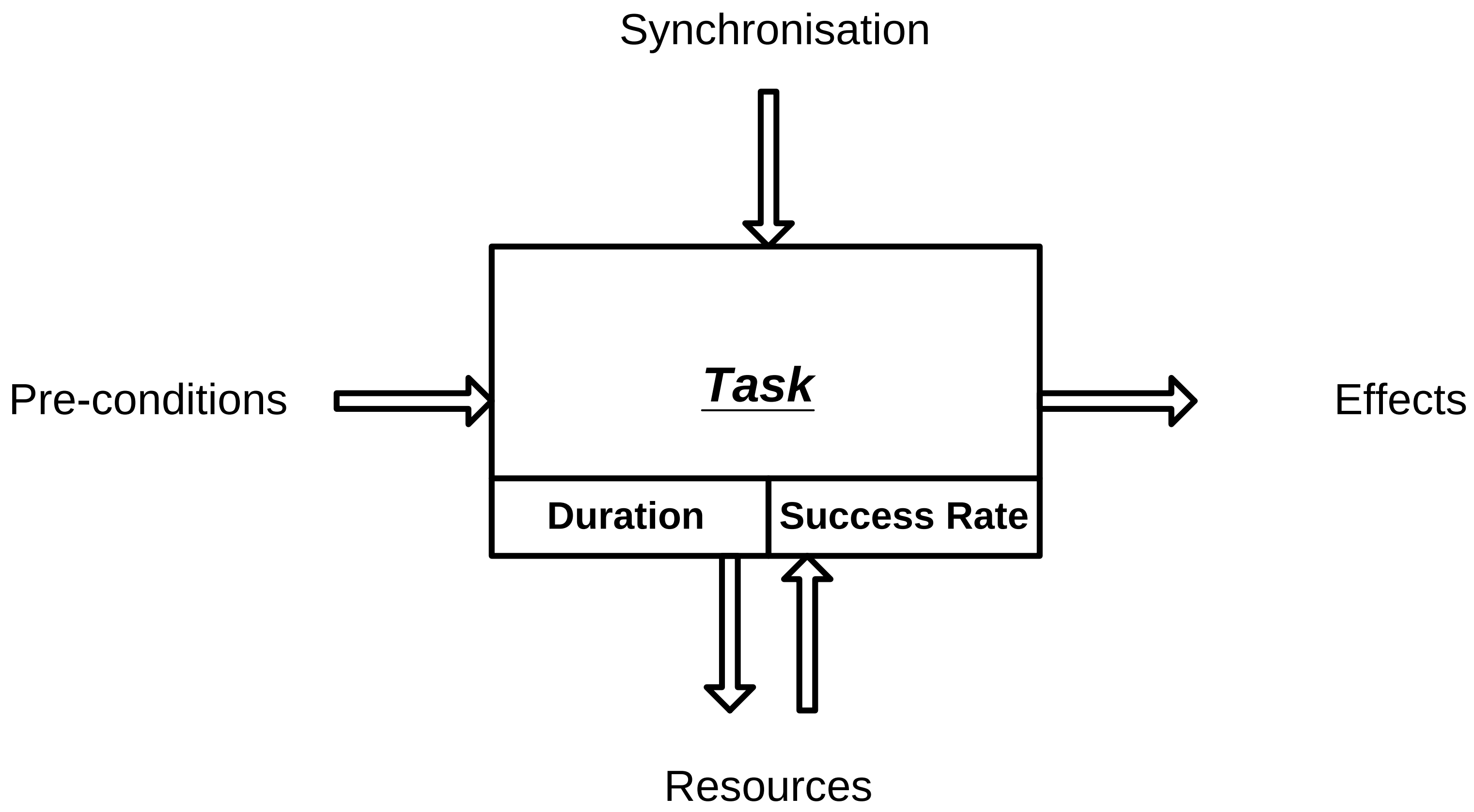
Modelling Considerations (cont.)

- A suitable and feasible course of action (COA) is a (partial) sequence of tasks that are
  - related through preconditions and effects,
  - constrained with resource and synchronisation considerations, and
  - lead to the achievement of conditions set in the end state.
- The COA is considered suitable because the execution of its tasks logically leads to the achievement of an end state
- The COA is considered feasible because the resource constraints are satisfied
- Note that temporal considerations for conditions and resources must also be captured for scheduling

Consistent with the Planning Doctrine (ADDP.5.0.1)

<table>
<tr><th>COG</th><th>CC</th><th>CR</th><th>CV</th><th>Effect</th><th>Method</th><th>Indicative Force Assignment</th><th>Pre-Conditions</th></tr>
<tr><td rowspan="7">Force Projection</td><td rowspan="7">Strategic Lift Capability</td><td rowspan="7">Transport A/C</td><td rowspan="4">CAP</td><td rowspan="3">Neutralise</td><td>OCA</td><td>FA18, A4, AAR</td><td>Intelligence
SEAD</td></tr>
<tr><td>Air Strike</td><td>F111</td><td>Intelligence
Escort
SEAD</td></tr>
<tr><td>SF Strike</td><td>Commando</td><td>Intelligence
SF deployed</td></tr>
<tr><td>Interdict</td><td>DCA</td><td>FA18, AAR</td><td>Continuous ISR
SADOC / Tactical Air C2)</td></tr>
<tr><td>Airfields</td><td>Cannot effect ROE</td><td>NIL</td><td>NIL</td><td>NIL</td></tr>
<tr><td rowspan="2">Ports</td><td rowspan="2">Blockade</td><td>MIO</td><td>NTG-FFH & Subs</td><td>Air defence</td></tr>
<tr><td>Mining</td><td>MCM Ships</td><td>Air Defence
Surface control
Subsurface control</td></tr>
</table>

A Conceptualisation of Tasks



COAST: Conduct amphibious assault

Conduct amphibious assault

Task Information

Task Duration: 4 Hours

Probability of Success 90%

Synchronisation:

- H-Hour

Preconditions:

- Local air control established
- Local sea surface control established
- Local sea sub-surface control established
- En route sea mines Cleared
- POE established

Conduct amphibious assault

- 2 X LPA
- 1 X LSH
- 6 X LCH
- 3 X BN

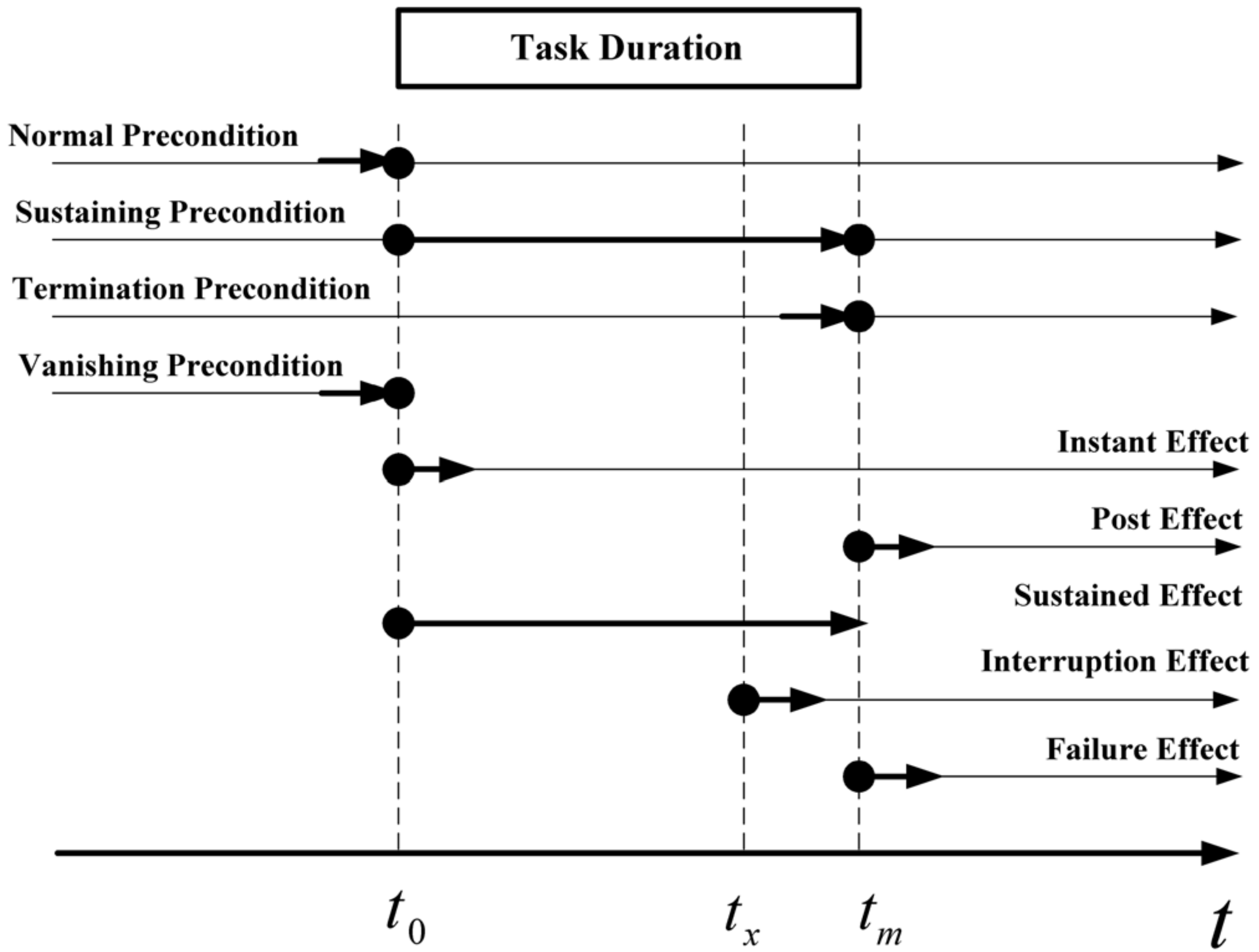
- 2 X LPA
- 1 X LSH
- 6 X LCH
- 3 X BN

Assigned Forces

Effects:

- Amphibious forces succesful landed

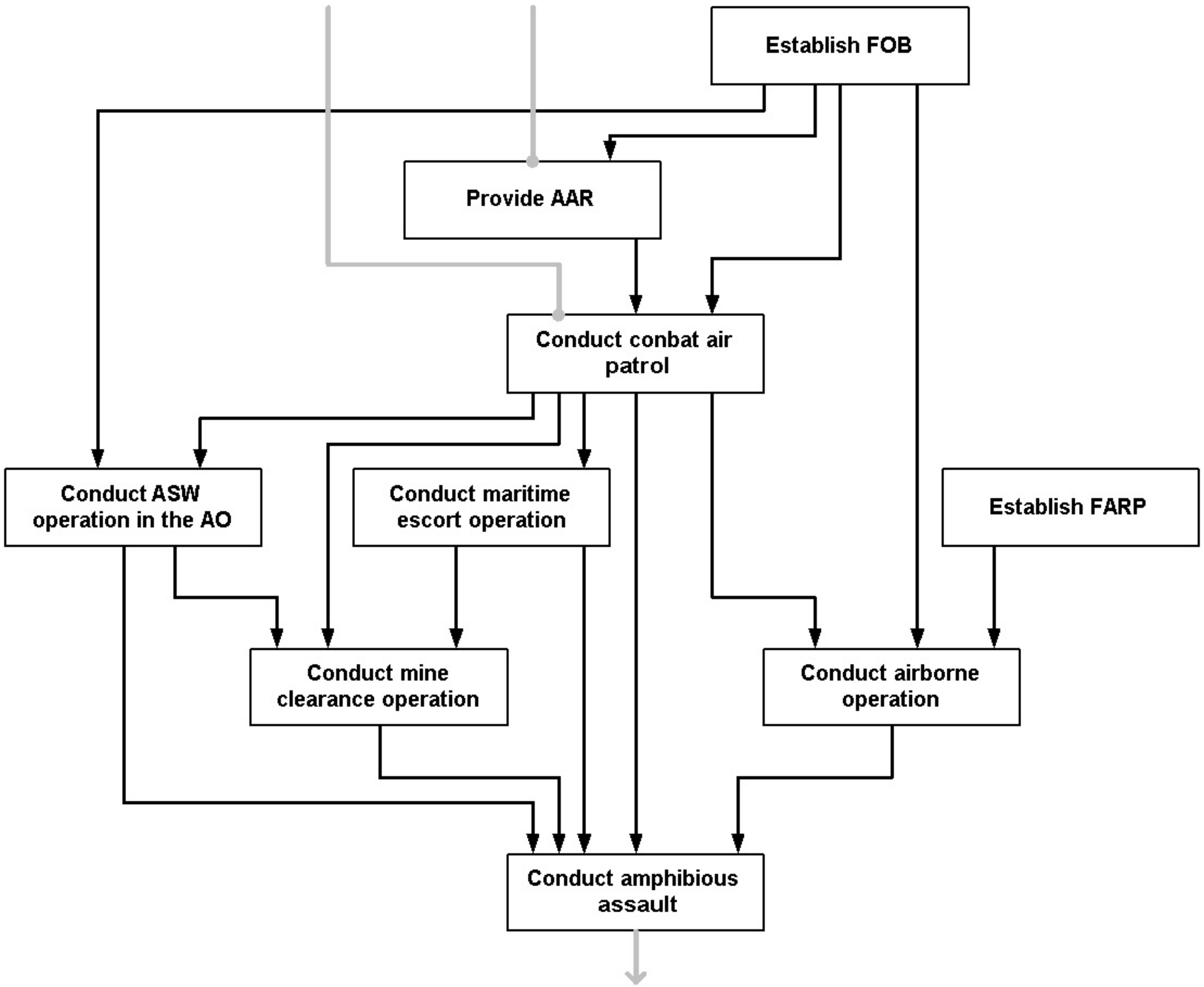
Temporal Aspects of Conditions



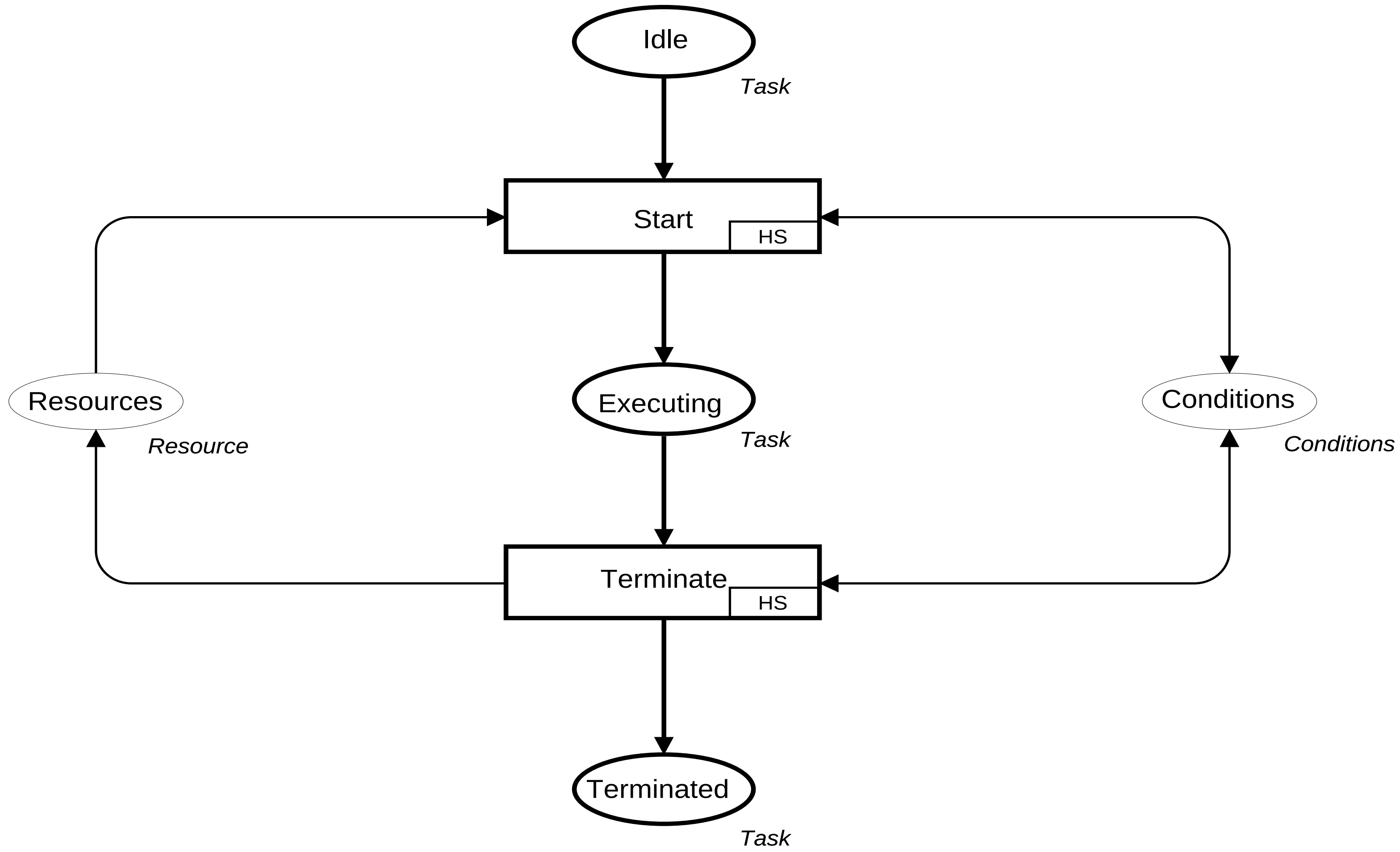
Instantiated Task Samples

Task name	Preconditions	Effects	Resources	Lost Res.	Duration	Sync. Info.	Success Rate
Conduct amphibious assault	▪Local air control established (SP) ▪Local sea surface control established (SP) ▪Local sea sub-surface control established (SP) ▪En route sea mines cleared (NP) ▪POE established (NP)	▪Amphibious forces successfully landed (PE)	2 LPA 1 LSH 6 LCH 3 BN		4 Hours	H-Hour	90%
Conduct combat air patrol	▪FOB established (NP) ▪Fighter aircraft deployed to the AO (NP) ▪En route refueling provided (SP)	▪Local air control established (SE)	12 FA 18	2 FA 18	As required		95%
Conduct ASW operations in the AO	▪FOB established (NP) ▪Local air control established (SP)	▪Local sea sub-surface control established (SE)	2 MPA		As required		95%
Conduct airborne operations	▪Local air control established (SP) ▪FOB established (NP) ▪FARP established (NP)	▪POE secured (PE)	12 Blackhawk 2 ABN BN	2 Blackhawk			95%
Conduct maritime escort operation	▪Local air control established (SP)	▪Local sea surface control established (SE)	4 FFH		As required		95%
Conduct mine clearance operation	▪Local air control established (SP) ▪Local sea surface control established (SP) ▪Local sea sub-surface control established (SP)	▪En route sea mines cleared (PE)	▪4 Mine Hunters		48 Hours		80%
Establish FOB		▪FOB established (PE)	▪1 ECSS		60 Hours	Now	100%
Establish FARP		▪FARP established (PE)	▪1 Eng Coy		40 Hours	Now	100%
Provide AAR	▪FOB established (NP) ▪AAR aircraft deployed to the AO (NP)	▪En route refueling provided (SE)	▪4 AAR		As required		99%

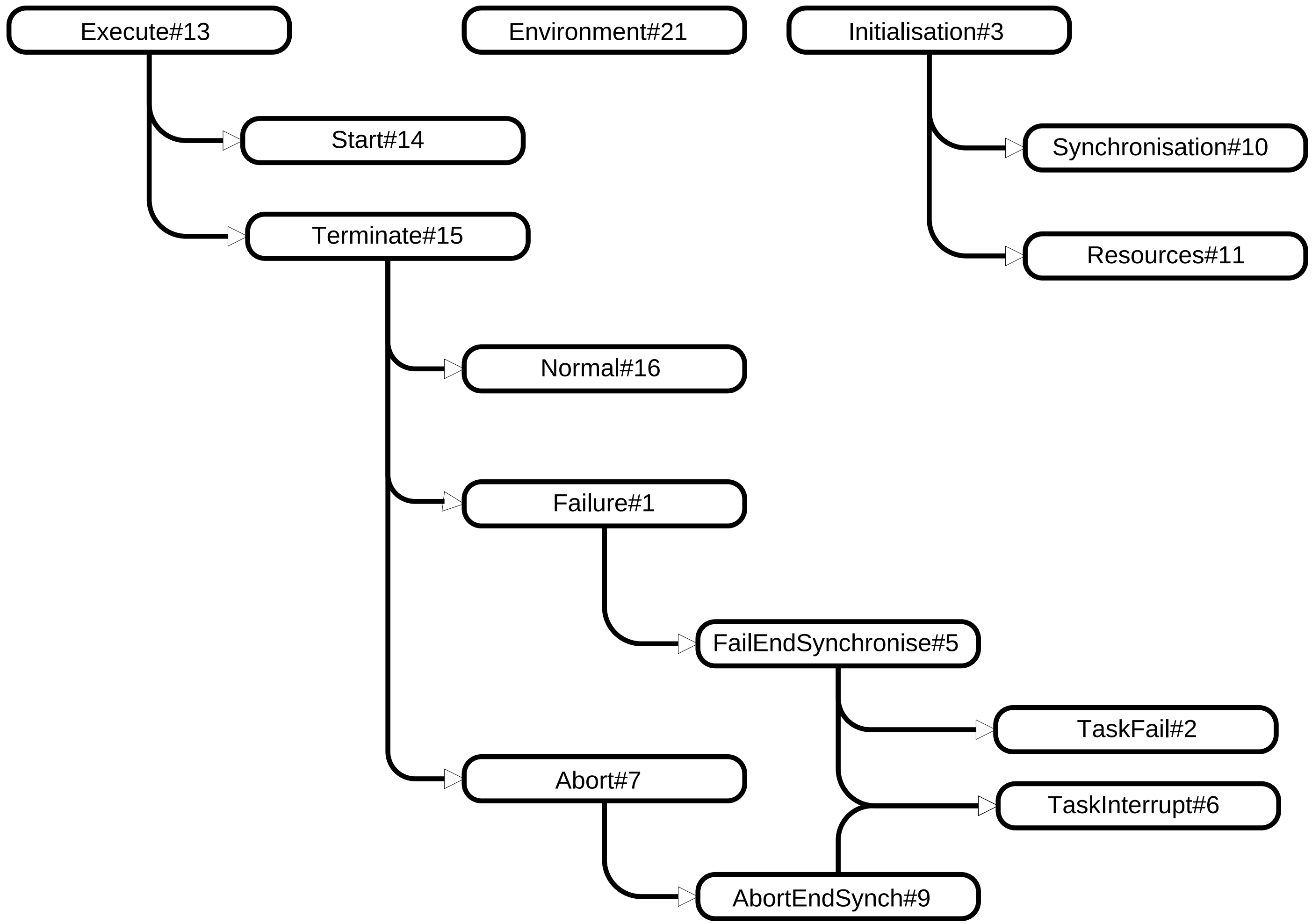
A Partial Sequence of COA Tasks



Formalising the Conceptual Model with Coloured Petri Nets

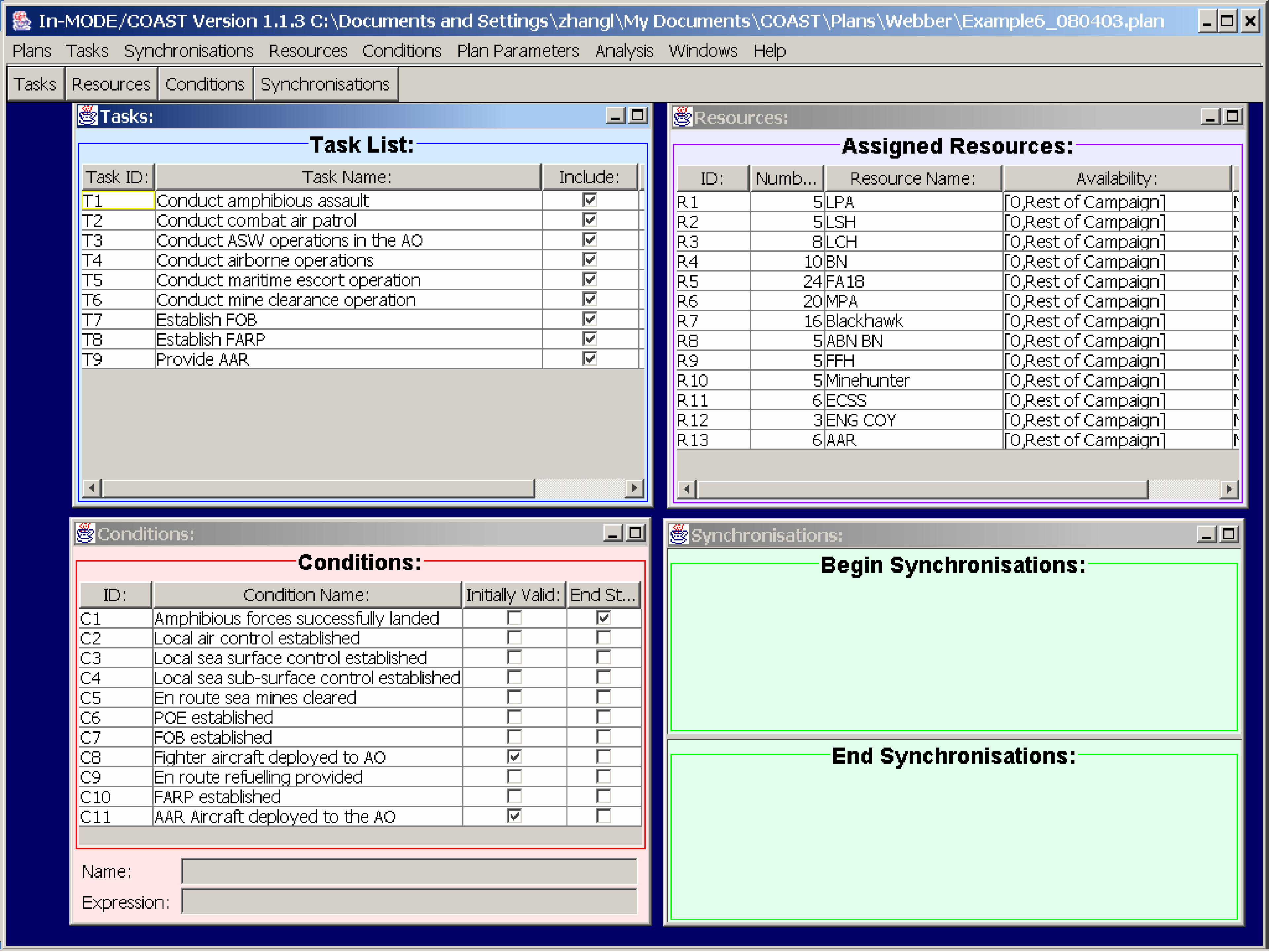


An Overview of the CPN Model



Model Execution and Analysis

- A Course of Action Scheduling Tool (COAST) was developed to perform model execution and analysis
- COAST has a client-server architecture
  - The client consists of a graphical user interface (GUI) that supports the COA task instantiation and conducts static analysis, i.e. consistency analysis and cause-effect analysis
  - The server uses the instantiated CPN model of COA tasks to conduct state space analysis for generating sequences and schedules of COA
- Novel state space analysis algorithms have been implemented in the COAST server


In-MODE/COAST Version 1.1.3 C:\Documents and Settings\zhangl\My Documents\COAST\Plans\Webber\Example6_080403.plan
Plans Tasks Synchronisations Resources Conditions Plan Parameters Analysis Windows Help
Tasks Resources Conditions Synchronisations
Tasks:
Task List:

Task ID:	Task Name:	Include:
T1	Conduct amphibious assault	☑
T2	Conduct combat air patrol	☑
T3	Conduct ASW operations in the AO	☑
T4	Conduct airborne operations	☑
T5	Conduct maritime escort operation	☑
T6	Conduct mine clearance operation	☑
T7	Establish FOB	☑
T8	Establish FARP	☑
T9	Provide AAR	☑

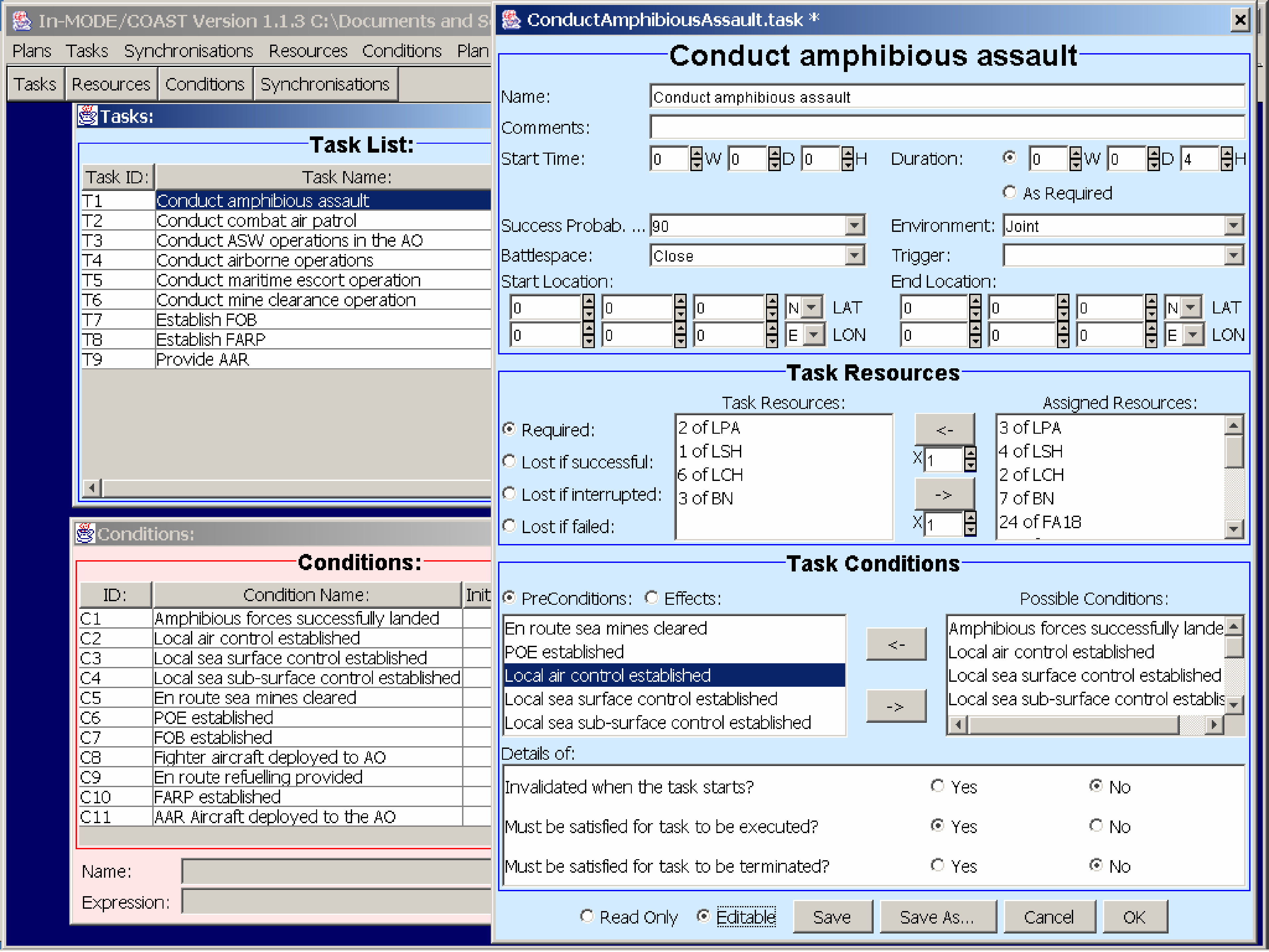
Resources:
Assigned Resources:

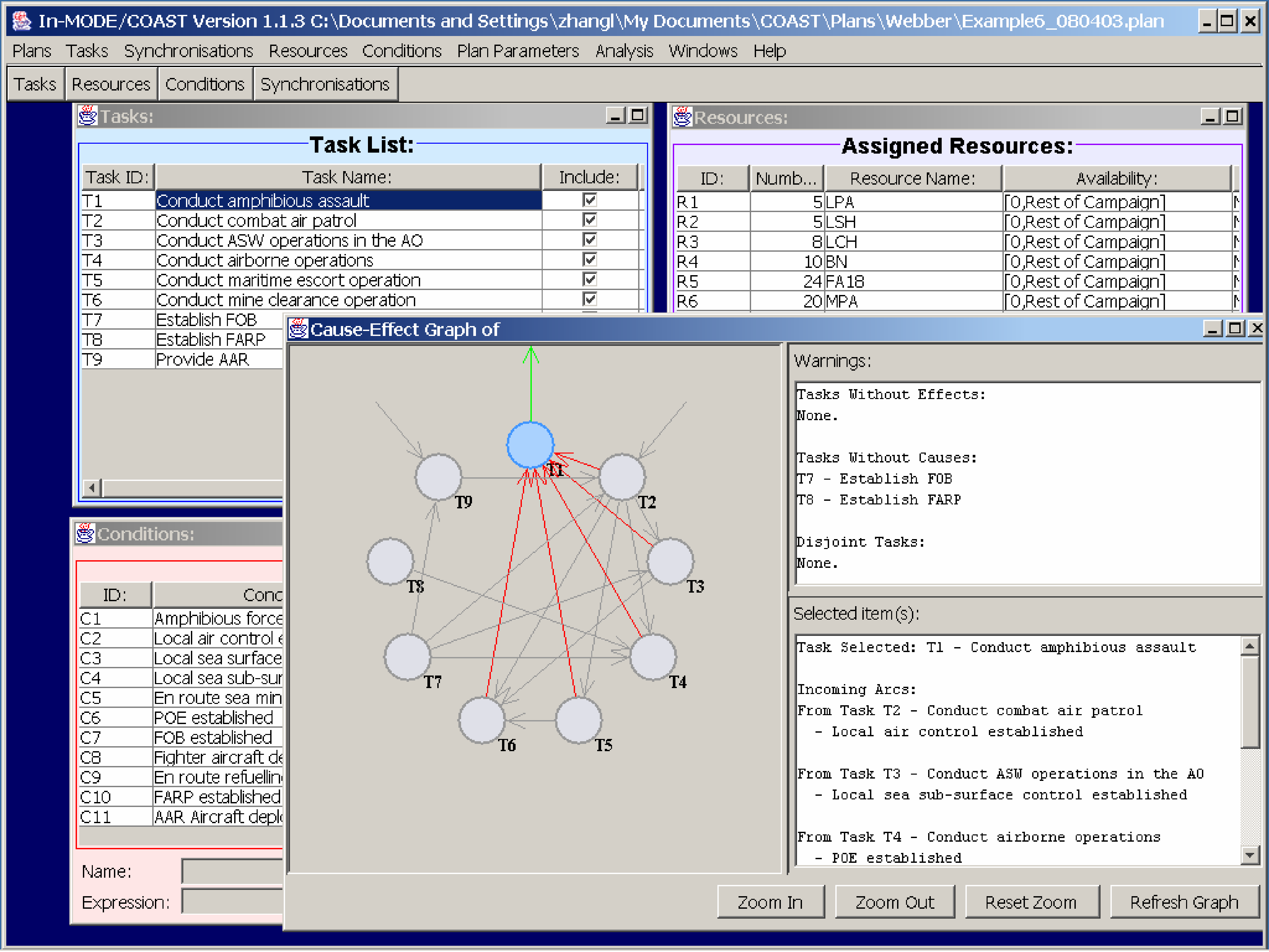
ID:	Numb...	Resource Name:	Availability:
R1	5	LPA	[0,Rest of Campaign]
R2	5	LSH	[0,Rest of Campaign]
R3	8	LCH	[0,Rest of Campaign]
R4	10	BN	[0,Rest of Campaign]
R5	24	FA18	[0,Rest of Campaign]
R6	20	MPA	[0,Rest of Campaign]
R7	16	Blackhawk	[0,Rest of Campaign]
R8	5	ABN BN	[0,Rest of Campaign]
R9	5	FFH	[0,Rest of Campaign]
R10	5	Minehunter	[0,Rest of Campaign]
R11	6	ECSS	[0,Rest of Campaign]
R12	3	ENG COY	[0,Rest of Campaign]
R13	6	AAR	[0,Rest of Campaign]

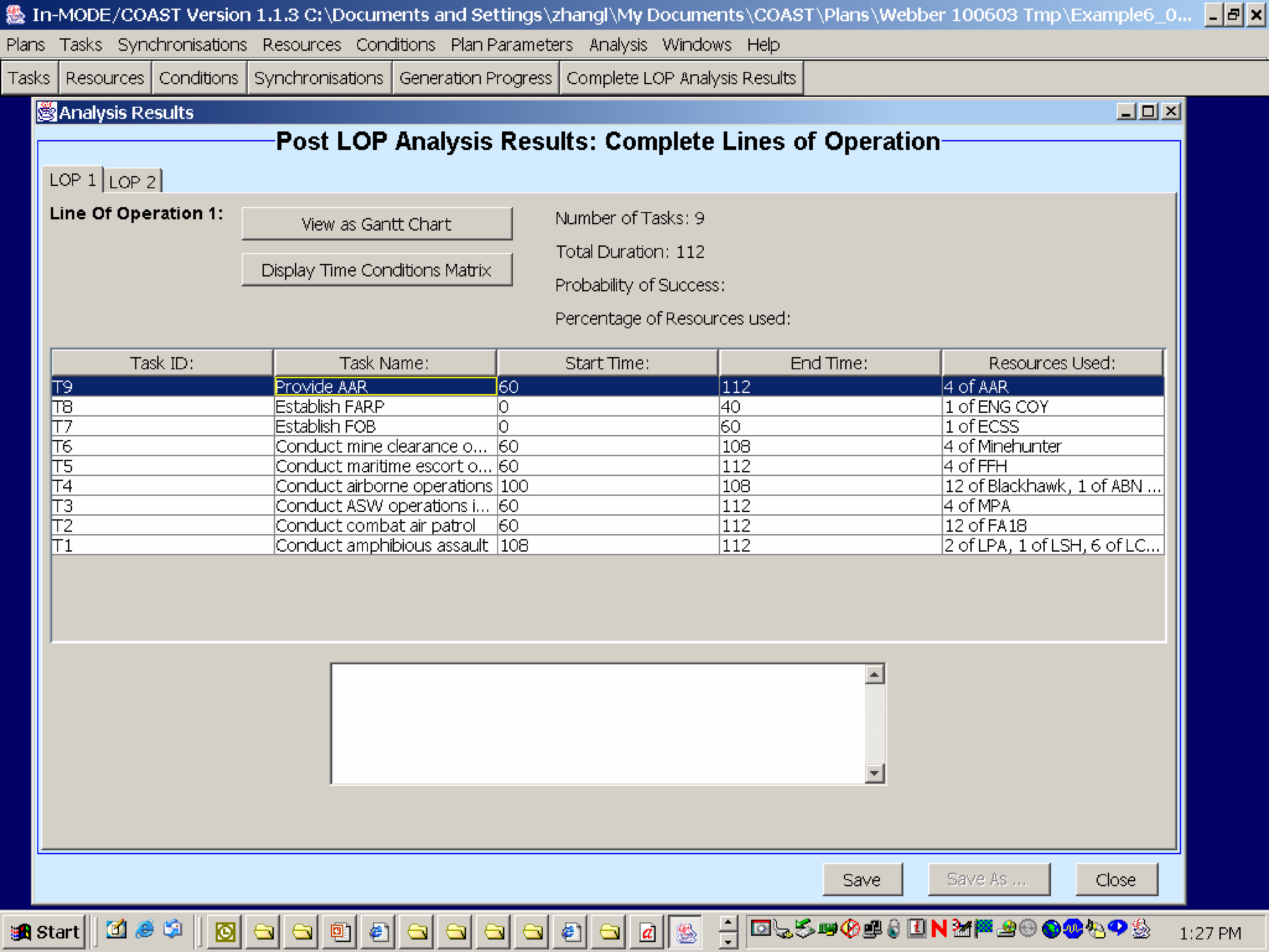
Conditions:
Conditions:

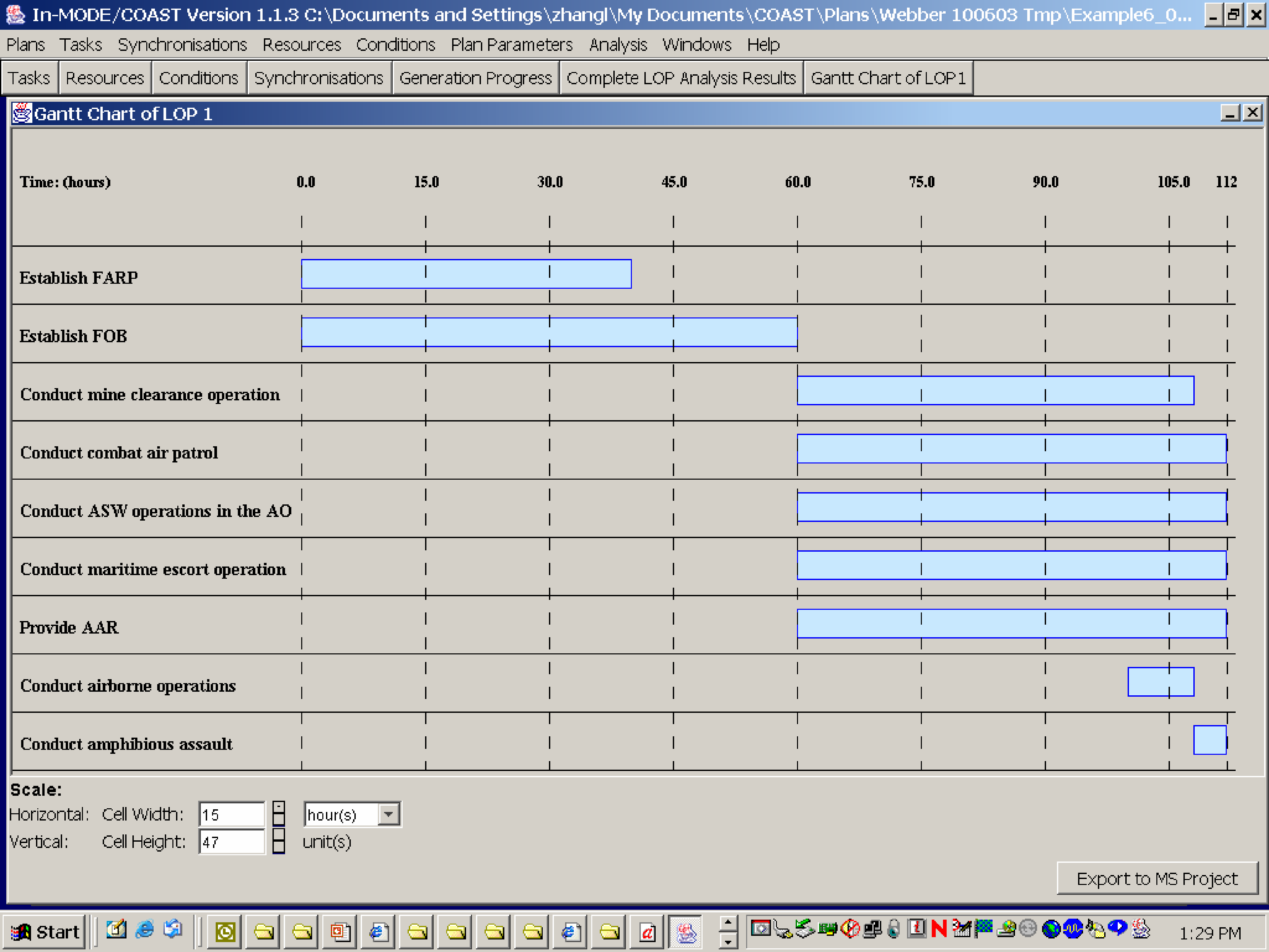
ID:	Condition Name:	Initially Valid:	End St...
C1	Amphibious forces successfully landed	☐	☑
C2	Local air control established	☐	☐
C3	Local sea surface control established	☐	☐
C4	Local sea sub-surface control established	☐	☐
C5	En route sea mines cleared	☐	☐
C6	POE established	☐	☐
C7	FOB established	☐	☐
C8	Fighter aircraft deployed to AO	☑	☐
C9	En route refuelling provided	☐	☐
C10	FARP established	☐	☐
C11	AAR Aircraft deployed to the AO	☑	☐

Name:
Expression:
Synchronisations:
Begin Synchronisations:
End Synchronisations:


In-MODE/COAST Version 1.1.3 C:\Documents and S
Plans Tasks Synchronisations Resources Conditions Plan
Tasks Resources Conditions Synchronisations
Tasks:
Task List:
Task ID: Task Name:
T1 Conduct amphibious assault
T2 Conduct combat air patrol
T3 Conduct ASW operations in the AO
T4 Conduct airborne operations
T5 Conduct maritime escort operation
T6 Conduct mine clearance operation
T7 Establish FOB
T8 Establish FARP
T9 Provide AAR
Conditions:
Conditions:
ID: Condition Name: Init
C1 Amphibious forces successfully landed
C2 Local air control established
C3 Local sea surface control established
C4 Local sea sub-surface control established
C5 En route sea mines cleared
C6 POE established
C7 FOB established
C8 Fighter aircraft deployed to AO
C9 En route refuelling provided
C10 FARP established
C11 AAR Aircraft deployed to the AO
Name:
Expression:
ConductAmphibiousAssault.task *
Conduct amphibious assault
Name: Conduct amphibious assault
Comments:
Start Time: 0 W 0 D 0 H
Duration: 0 W 0 D 4 H
As Required
Success Probab. ... 90
Environment: Joint
Battlespace: Close
Trigger:
Start Location:
0 0 0 N LAT
0 0 0 E LON
End Location:
0 0 0 N LAT
0 0 0 E LON
Task Resources
Task Resources:
Assigned Resources:
Required:
Lost if successful:
Lost if interrupted:
Lost if failed:
2 of LPA
1 of LSH
6 of LCH
3 of BN
<-
X 1
->
X 1
3 of LPA
4 of LSH
2 of LCH
7 of BN
24 of FA18
Task Conditions
PreConditions: Effects:
Possible Conditions:
En route sea mines cleared
POE established
Local air control established
Local sea surface control established
Local sea sub-surface control established
<-
->
Amphibious forces successfully lande
Local air control established
Local sea surface control established
Local sea sub-surface control establis
Details of:
Invalidated when the task starts? Yes No
Must be satisfied for task to be executed? Yes No
Must be satisfied for task to be terminated? Yes No
Read Only
Editable
Save
Save As...
Cancel
OK


In-MODE/COAST Version 1.1.3 C:\Documents and Settings\zhangl\My Documents\COAST\Plans\Webber\Example6_080403.plan
Plans Tasks Synchronisations Resources Conditions Plan Parameters Analysis Windows Help
Tasks Resources Conditions Synchronisations
Tasks:
Task List:
Task ID: Task Name: Include:
T1 Conduct amphibious assault
T2 Conduct combat air patrol
T3 Conduct ASW operations in the AO
T4 Conduct airborne operations
T5 Conduct maritime escort operation
T6 Conduct mine clearance operation
T7 Establish FOB
T8 Establish FARP
T9 Provide AAR
Resources:
Assigned Resources:
ID: Numb... Resource Name: Availability:
R1 5 LPA [0,Rest of Campaign]
R2 5 LSH [0,Rest of Campaign]
R3 8 LCH [0,Rest of Campaign]
R4 10 BN [0,Rest of Campaign]
R5 24 FA18 [0,Rest of Campaign]
R6 20 MPA [0,Rest of Campaign]
Conditions:
ID: Conc
C1 Amphibious force
C2 Local air control e
C3 Local sea surface
C4 Local sea sub-sur
C5 En route sea min
C6 POE established
C7 FOB established
C8 Fighter aircraft de
C9 En route refuellin
C10 FARP established
C11 AAR Aircraft depl
Name:
Expression:
Cause-Effect Graph of
T1
T2
T3
T4
T5
T6
T7
T8
T9
Warnings:
Tasks Without Effects:
None.
Tasks Without Causes:
T7 - Establish FOB
T8 - Establish FARP
Disjoint Tasks:
None.
Selected item(s):
Task Selected: T1 - Conduct amphibious assault
Incoming Arcs:
From Task T2 - Conduct combat air patrol
- Local air control established
From Task T3 - Conduct ASW operations in the AO
- Local sea sub-surface control established
From Task T4 - Conduct airborne operations
- POE established
Zoom In Zoom Out Reset Zoom Refresh Graph


In-MODE/COAST Version 1.1.3 C:\Documents and Settings\zhangl\My Documents\COAST\Plans\Webber 100603 Tmp\Example6_0...
Plans Tasks Synchronisations Resources Conditions Plan Parameters Analysis Windows Help
Tasks Resources Conditions Synchronisations Generation Progress Complete LOP Analysis Results
Analysis Results
Post LOP Analysis Results: Complete Lines of Operation
LOP 1
LOP 2
Line Of Operation 1:
View as Gantt Chart
Display Time Conditions Matrix
Number of Tasks: 9
Total Duration: 112
Probability of Success:
Percentage of Resources used:
Task ID: | Task Name: | Start Time: | End Time: | Resources Used:
T9 | Provide AAR | 60 | 112 | 4 of AAR
T8 | Establish FARP | 0 | 40 | 1 of ENG COY
T7 | Establish FOB | 0 | 60 | 1 of ECSS
T6 | Conduct mine clearance o... | 60 | 108 | 4 of Minehunter
T5 | Conduct maritime escort o... | 60 | 112 | 4 of FFH
T4 | Conduct airborne operations | 100 | 108 | 12 of Blackhawk, 1 of ABN ...
T3 | Conduct ASW operations i... | 60 | 112 | 4 of MPA
T2 | Conduct combat air patrol | 60 | 112 | 12 of FA18
T1 | Conduct amphibious assault | 108 | 112 | 2 of LPA, 1 of LSH, 6 of LC...
Save
Save As ...
Close
Start
1:27 PM


In-MODE/COAST Version 1.1.3 C:\Documents and Settings\zhangl\My Documents\COAST\Plans\Webber 100603 Tmp\Example6_0...
Plans Tasks Synchronisations Resources Conditions Plan Parameters Analysis Windows Help
Tasks Resources Conditions Synchronisations Generation Progress Complete LOP Analysis Results Gantt Chart of LOP 1
Gantt Chart of LOP 1
Time: (hours)
0.0
15.0
30.0
45.0
60.0
75.0
90.0
105.0
112
Establish FARP
Establish FOB
Conduct mine clearance operation
Conduct combat air patrol
Conduct ASW operations in the AO
Conduct maritime escort operation
Provide AAR
Conduct airborne operations
Conduct amphibious assault
Scale:
Horizontal: Cell Width: 15 hour(s)
Vertical: Cell Height: 47 unit(s)
Export to MS Project
Start
1:29 PM

COAST and MS Project

Functions and Features			MS Project	COAST
Scheduling	Per causal relationships		-	+
	Per temporal relationships		+	+
	Per resource constraints		-	+
	Multiple lines of operation		-	+
Analysis	Probability of Success		-	↑
	Risk to capabilities		-	↑
	Critical path		+	+
	Cost		+	+
Optimisation	Per above criteria, i.e., probability of success, risk, cost		-	↑
Views	GANTT		+	+
	PERT		+	+
	Tailored Views	Cause-Effect Diagrams	-	+
		Decisive Points	-	↑
		Decision Points	-	↑
		Desired military end state	-	+

Legend

+ Available

- Unavailable

↑ Under development

Note: COAST Schedules can be exported to MS Projects for analysis, views and reporting.

Discussions

- A method of describing operational level COA in terms of an end state, timed tasks, required and consumed resources, preconditions and effects of tasks
- A method of analysing tasks to determine if a desired military end state can be achieved given the assigned resources
- Methods of generating plans that can achieve the desired end state;
- A user interface that does not rely on an understanding of the formal methods employed by the tool; and
- A mathematical representation of COA lending to quantitative COA analysis and optimisation

Future Work

- Characterisation of the dynamic system realised from the CPN model, e.g., how does it relate to timed automata
- Stochastic overlay and characterisation
- Metrics of operational-level COA, e.g., probability of success, cost, loss of capabilities
- Quantitative analysis and optimisation
  - Dynamic programming techniques
  - AI planning techniques